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SENSOR DEVELOPMENT THERMOSPHERIC NEUTRAL WIND MEASUREMENTS

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14. ABSTRACT
This report describes progress made in the development of novel new sensors to measure the thermospheric neutral wind velocity from space. The measrements depend upon the supersonic velocity of the spacecraft to determine a velocity vector from measurement of the kinetic energy of the gas along the sensor look direction and the angle of arrival of the gas with respect to that look direction. Two sensors are utilized; one to measure the kinetic energy of the gas and another to measure the arrival angle. The arrival angle is determined from the differential pressure in two adjacent chambers with small entrance apertures. Different pressures in each chamber result from different angles of attack with respect to the chamber apertures. The kinetic energy of the gas with repsect to the sensor normal is measured by examining the ions resulting from ionization of the neutrals that flow, undisturbed through an ion source. During this period of activity flight sensores have been designed and constructed for operation as part of the Air Force C/NOFS mission. Pre-flight performance simulation and verification has also been undertaken.

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Contents

List of Figures

1. INTRODUCTION

The challenge we have addressed is a specification of the dynamics of the ionosphere and thermosphere during times when severe radio scintillation occurs. This specification must include a description of the neutral air wind velocity and the ambient ion drift. In previous reports we have described the operating principles behind a derivation of the in-situ neutral wind and ion drift velocity from satellite borne instruments. In both cases, two sensors are required. One to measure the arrival angle of the gas with respect to the senor look direction and another to measure the velocity of the particle species along the sensor look direction. The techniques employed to measure the neutral arrival angle require the construction of rugged Bayert-Alpert pressure gauges that are utilized to make differential measurements in two adjacent pressure chambers. The chamber apertures are directed approximately, but not exactly, along the ram direction. Since the satellite orbital velocity is supersonic the pressure in the chambers is enhanced by a factor of about 20 over the ambient pressure, but nevertheless the operating pressure range for the C/NOFS mission is quite low and the pressure gauges must be carefully designed. The velocity of the particle species in the look direction of the sensor is determined by measuring the energy distribution of ionized neutral gas that flows, unimpeded through the sensor. Since the ionization efficiency is quite low an electron multiplier is used to amplify the ion current that is detected behind a grid that controls the energy of the ions that may pass through it. This same device is sensitive to ultra-violet photons. Thus, an electrostatic deflection system is employed to direct the ion beam away from the sensor look direction, which is hidden from direct or singly reflected photons. Previous reports have described the operating principles and the proposed instrument design and during this activity period we have been able to determine the expected performance characteristics of the instrumentation both by analysis and laboratory tests.

2. INSTRUMENTATION

Two sensors have been designed and prepared for flight on the C/NOFS payload. The cross-track wind sensor (CTS) measures the arrival angle of the neutral gas with respect to the ram direction and the ram wind sensor (RWS) measures the velocity of the neutral gas along the ram direction. The performance characteristics of each of these sensors is described below.

2.1 Cross-Track Sensor

The cross-track wind sensor is a differential pressure gauge that measures the neutral gas arrival angle by determining the ratio of the pressures in two adjacent pressure chambers that have small apertures facing the ram direction. Figure 1 is a schematic illustration of the principle s of operation making use of the simple relationship between the pressure ratio, obtained by taking the difference between outputs proportional to the logarithm of the pressure, and arrival angle of the gas.

$$V_d = G_d C \ln\left(\frac{P_1}{P_2}\right) = G_d C \ln\left(\frac{\cos(\alpha - \varepsilon)}{\cos(\alpha + \varepsilon)}\right)$$

(1)

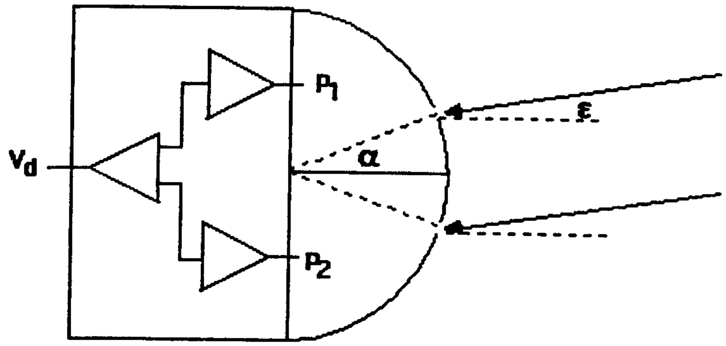

Figure 1. Schematic illustration of arrival-angle measurement scheme.

Figure 2 shows photographs of the front and rear of the pressure chamber assemblies that comprise the flight configuration. A ruggedized Bayard-Alpert pressure gauge allows for the simplest measure of pressure over the required range and can be easily constructed in a miniature package with redundant hot filaments for the ionization source.

Figure 2. Flight configuration of pressure chambers and attached pressure gauges.

The gauge enclosure is designed to ensure that no streaming ambient gas has access to the gauge. Thus the gas inside the chamber is in equilibrium with the chamber walls and is enhanced over the ambient pressure by virtue of the supersonic satellite velocity. Figure 3 illustrates the configuration of the filament and grids inside the gauge assembly.

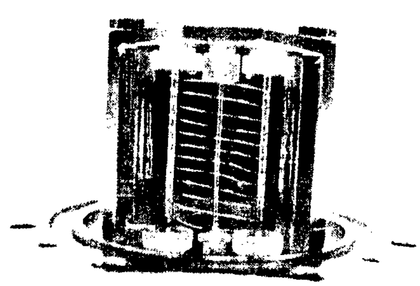

Figure 3. Ruggedized Bayert-Alpert Gauge used for pressure measurement.

To simulate and verify the expected performance of this arrangement we must individually establish the behavior of the gauge and its associated logarithmic electrometer and of the difference amplifier used to determine the pressure ratio. In flight the very low-pressure environment at apogee will provide ample opportunity to outgas the sensor components. However, within the pressure regime attainable in the laboratory we are able to verify that the gauges behave as expected. The expected system performance is illustrated in Figure 4 where the difference amplifier output for a given current ratio is plotted along with the ratio expected from calculations.

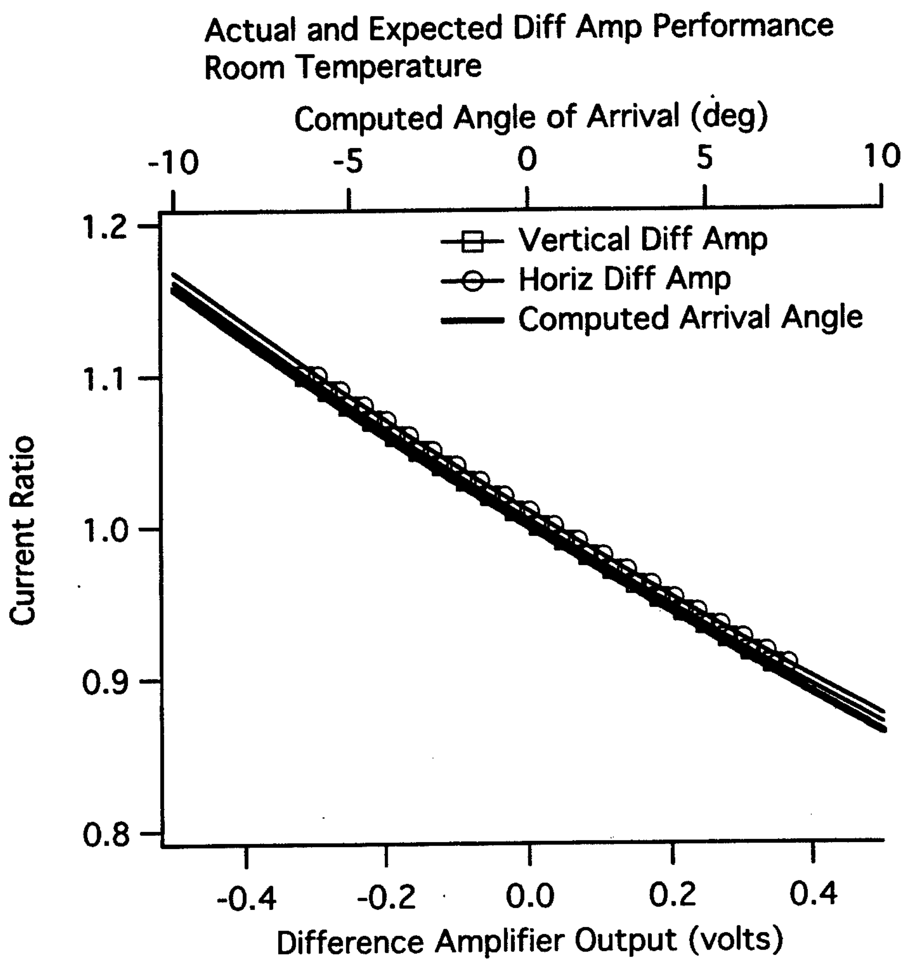

Figure 4. Expected and derived output from the CTS sensor.

In summary, the laboratory performance of the CTS is consistent with expectations. It is clear that the instrument will perform well when the ambient pressure is greatest. Thus we expect satisfactory performance on C/NOFS for altitudes below 450 km.

2.2 Ram Wind Sensor

The ram wind sensor derives the velocity along the ram direction by performing a retarding potential energy analysis on an ionized fraction of the flowing neutral gas. The incident ambient ions are electrostatically deflected from the instrument axis so that only the ions produced from the flowing neutral beam have access to the electron multiplier detector. Figure 5 shows a photograph of the flight hardware designed for C/NOFS.

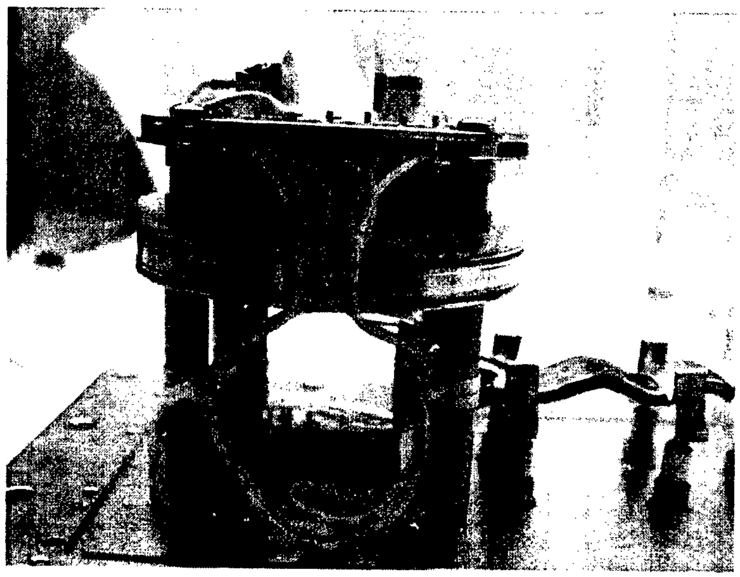

Figure 5. Ram Wind Sensor for CINDI-C/NOFS

While it was previously verified that this configuration was capable of detecting the signal from an ionized neutral stream, the flight configuration remained unverified as did the analysis techniques to be employed in reducing the flight data. During this reporting period, both these deficiencies have been removed. By utilizing a "draw-out" potential inside the sensor we are able to provide ions exiting the source with different energies without requiring a supersonically flowing neutral beam. We have also developed the necessary software to execute the least-squares analysis of the data to provide the ram energy of the ions. Figure 6 shows the results of this exercise. In this figure is shown three retarding potential characteristics obtained while the draw-out potential was respectively 5, 6, and 7 volts. For the first curve we have utilized an effective satellite velocity of 5.5 km/sec to provide the approximate kinetic energy of the beam. A fit to this data yields an aperture potential near zero as expected and a gas temperature of about 780 K. Fits to the following curves show that each is displaced in energy characterized by the aperture potential by about 1 volt. Some variability in the temperature is apparent due in part to the poor specification of the effective vehicle motion and in part to the inclusion of the tail of the I-V characteristic in the fitting procedure. Given these limitations it is gratifying to see the relatively clean signal and the derivation of the energy displacements as expected. In flight performance at these levels will lead to unprecedented fidelity in the specification of neutral drifts in the upper atmosphere.

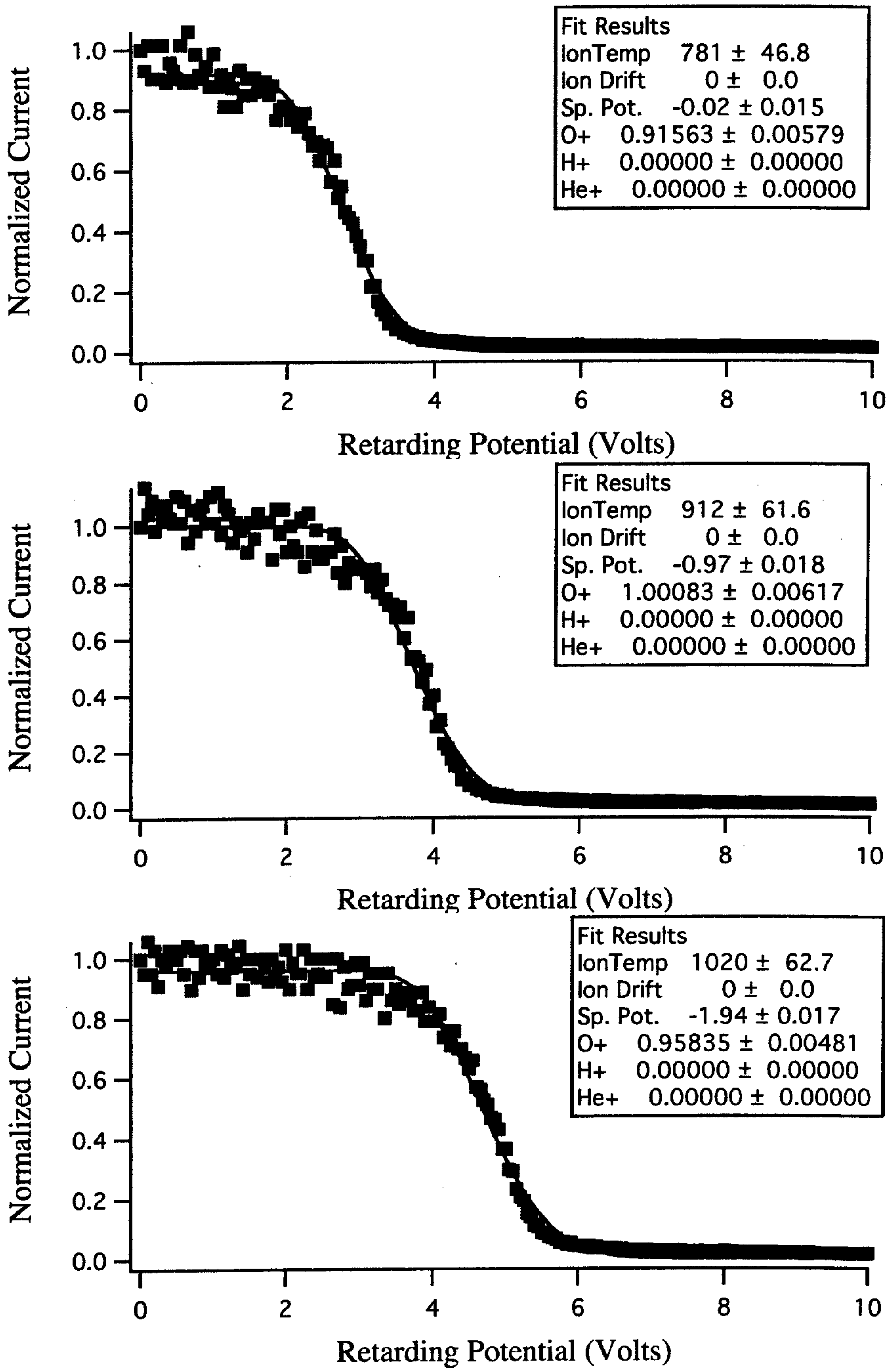

Figure 6. Ram Wind Sensor RPA Characteristics with fitted results.

3. CONCLUSIONS

This research effort has resulted in the design and verification of a robust space instrument to measure the F-region neutral wind vector. The performance evaluation and verification work described here has been part of the overall effort to provide flight hardware and software for satellite borne instrumentation. All our success criteria at this level have been met. We can now confidently look forward to obtaining essential measurements of the equatorial F-region neutral wind during the C/NOFS program.